A MAINTENANCE MANAGEMENT MODEL FOR HV SUBSTATIONS IN THE FRAMEWORK OF THE NEW ELECTRIC MARKETS

José L. MARTINEZ
Edenor S.A. - Argentina
jmartinez@edenor.com

ABSTRACT

The present context of the electric industry, characterized by competitive markets and strict regulatory technical requirements to fulfill, leads to electric utilities to optimize the maintenance management, developing their activities both, more effectively and with lower costs.

This paper describes a management model for the maintenance of HV transformer substations developed by Edenor, the largest Argentine electric distribution utility. Such model is based on a number of key drivers: the modeling of the HV network in "modules of maintenance", the development of Work Programs for all the equipment installed, the setting of critical levels criterions and the monitoring of results. In addition, a strong emphasis was put on the development of proactive maintenance tasks, aiming at reducing maintenance outages.

By the development of this model, positive results were reached, as regards the optimization of the maintenance management, availability and reliability of installations and reduction of costs.

INTRODUCTION

The transformation of the electric markets happened at the beginning of the 90s world-wide requires assuring the reliability and availability of the electric systems, which represents a key factor in the maintenance strategies to be developed nowadays by the electric distribution utilities.

Into this framework, Edenor is an Argentine utility that distributes electricity in the northern area of Buenos Aires city and the northwestern part of the greater Buenos Aires, in a market of 4.637 km^2 and a 7 million inhabitants population, about 20% of the Argentine population. With 2.5 million clients and a billed annual energy of 17,886 GWh, Edenor is the largest Argentine electric distribution company, in terms of number of customers and energy sold.

Among its facilities it has 1,338 km of HV networks in 220 and 132 kV and 67 HV transformer substations, with 12,994 MVA of HV/HV and HV/MV transformation power.

Since its privatization in the 90s, the company has developed its activities in a competitive environment in a regulated market, with strict technical requirements by the regulatory authorities and the imposition of severe penalties for its non-fulfillment.

This new scenery, influenced by an increasing demand of networks with equipment operating at the limit of its capability, a lower redundancy of systems, operating restrictions that limit maintenance outages and incomes tied to the availability of the installations, drove to the company to find new ways to develop its activities both, in a more effective way and with lower costs.

In the stated situation, radical changes in the way of thinking concerning the maintenance activities are required; the challenge is to develop enhanced strategies and management tools.

APPROACH TO A NEW MAINTENANCE MODEL

To deal with the new context of the business, Edenor has re-considered the entire maintenance policies performed so far, to improve their management, aiming at maximizing both, the availability and reliability of its installations, so as to reach the supply quality levels required with profitability and keeping at the same time acceptable levels of risk.

In order to do so, attention was focused on HV transformer substations equipment, where maintenance is usually more specific due to its critical role in networks to assure the operation of the distribution systems.

Therefore, the guidelines of an optimized management model for the maintenance of HV substations were drawn up.

The core of this maintenance model was based on a number of key drivers: the modeling of the HV network in "*modules of maintenance*", the development of Work Programs for all the equipment installed, the setting of critical levels criterions to identify the condition of the equipment and the systematic monitoring and evaluation of the obtained results (*Fig. 1*).

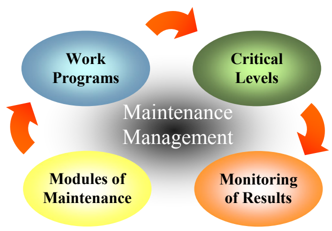

Fig. 1 - Key Drivers of the Maintenance Management Model

Modules of Maintenance

The so called *"modules of maintenance"* represent the minimum part of the installation that can be taken out of service to perform maintenance tasks on any involved equipment.

Analyzing the topology of the network and unbundling it in functional units, defining both, the component items (power transformer, circuit-breaker, disconnector, instrument transformer, surge arrester) and their physical location, *"modules of maintenance"* were defined, considering that to perform maintenance tasks in an item of a module, such module must be taken out of service as a whole (*Fig. 2*).

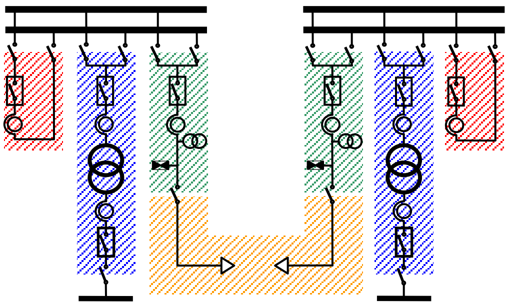

Fig. 2 - Modules of Maintenance

The most common functions of such modules are transmission lines, feeders, busbar coupling, transformation, reactive compensation, etc. These modules can be linked among them establishing sets of "linked modules", which are modules physically associated to fulfill one or more electric functions into the network. Depending on their function, such linked modules can be either, simple or complex ones.

Simple sets have just one function; they extend between two substations and are composed up to three modules. An example is a set made up of a transmission line connected between two main substations and its two switching modules (busbar disconnectors and circuit-breaker). The outage of any of them, brings about the unavailability of the set as a whole.

Complex sets have more than one function; they consist of three or more simple modules and involve at least two substations. Depending on the module affected, its outage can cause or not the entire unavailability of the set. In example, in a transmission line between two main substations that besides feeds secondary substations, the loss of one switching module does not cause the unavailability of the line as feeder of the secondary substations; in the same way, the outage of the transformation modules does not affect the transmission function of the line. In contrast, taking out of service the transmission line causes the unavailability of the whole set.

Under this concept, when an installation is required to be out of service for maintenance, by modeling the HV network splitting it in *"modules of maintenance*" the maintenance planning can be optimized, taking advantage of the programmed outages to perform maintenance tasks, improving so the use of resources and increasing the availability of the installations.

Development of Work Programs

For every physical asset in service different preventive and predictive maintenance Work Programs (WPro) were defined. The WPro are a task list to be executed on a certain item when both, its condition indicate it or a parameter of control has reached a limit. Such parameter can be time (in case of scheduled maintenance), number of operations, accumulated kA or others. In the WPro, the tasks to perform and all the necessary specifications for its execution are described, as well as the required resources. In addition, a number of Technical Procedures define how to execute every maintenance task.

Every WPro were developed from the available experience, taking into account the knowledge acquired in field, surveying the existing practices and performing a Failure Mode Effects and Criticality Analysis (FMECA) for the entire physical asset to be maintained. From this evaluation, light and reinforced maintenance WPro were established.

The tasks to execute can also include measures or tests. In this case, acceptable threshold values were specified, in order to analyze "in field" the parameters under control and detect possible deviations.

In the development of the WPro, the concept of "*Out of Range*" task was introduced, to identify abnormalities or measures detected out of their admitted limit values.

According to the obtained results, the item condition is labeled. In case of detecting any anomaly, the priority of intervention is defined, depending on different critical levels.

Setting of Critical Levels

To identify the condition of the equipment, a six-group-classification code was defined, according to the following verification criterion:

0. *No Out of Range situations*, corrective actions are not required. The item is in good condition.
1. *Critical Out of Range situations* which solution must be "Immediate". Otherwise, the item must be labeled as not available, for affecting the safety of people and installations, and the quality of supply.
2. *Serious Out of Range situations* which solution must be "Priority"; the item can remain in service, but requiring a maintenance task as soon as possible.
3. *Moderate Out of Range situations* which solution can be "Programmed"; the item can remain in service, but requiring a maintenance task the next scheduled outage.
4. *Tolerable Out of Range situations* that allow keeping the item in service as Observed.
5. *Out of Range situations no attributed to an abnormality or measured value detected*; the solution requires modifying the WPro.

The setting of different critical levels allows, in case of detecting *Out of Range* values or abnormalities, labeling the condition of the equipment to control its evolution and address the necessary actions if major maintenance tasks are required, to restore its condition to a satisfactory level.

Monitoring of Results

To support the maintenance management and the decision making process, a corporate computing system was internally developed.

The core of this supporting tool is based on a database, where all the equipment to be maintained was inventoried, identifying it *logically* according to its location in the network (i.e. substation 065, feeder 636, circuit-breaker) and *physically*, by the nameplate data (manufacturer, model, type, rated parameters, serial number, manufacturing year) and an alphanumeric code that identifies the item unequivocally.

This software provides workflow functions, work orders issuing and tracking and data storage (i.e. background, results of measures and tests executed, maintenance records and condition data of the equipment), that helps for the planning and programming of the maintenance activities.

Through this decision support system, a number of computing queries allows obtaining information such as evolution and trends of measures and critical parameters, *Out of Range* situations and their criticality, equipment with delayed maintenance tasks, etc.

Based on a Data Mining concept approach [1], dynamic outputs are used in the decision making process for the maintenance management, extracting trends and patterns from the data obtained as well as knowledge-based rules, monitoring the evolution of the abnormalities detected to prioritize the corrective actions to be performed and evaluating the obtained results in a systematic way.

USE OF PROACTIVE MAINTENANCE STRATEGIES

Traditionally, the approach of HV substations maintenance used to be mainly conservative, based on standard and strictly determined scheduled interventions, in general influenced by manufacturers' instructions. This approach was expensive in terms of resources required and unavailability of installations for maintenance.

As a consequence, searching for reducing maintenance outages, a strong emphasis was put in the increase of more proactive maintenance tasks, supported by intensive man-made inspections.

Therefore, several on-line techniques based on periodic inspections are used to assess the equipment's technical condition, in terms of dielectric, thermal and mechanical aspects [2]. In many cases, they allow to define weather the item has to be taken out of service for maintenance or not.

Dielectric condition, trends and patterns are mostly attended by ultra high frequency (UHF) and partial discharges (PD) detection as well as tangent delta (tg δ) measuring.

DGA (Dissolved Gas Analysis) is carried out in power transformers on an annual basis, to diagnose their condition and detect internal anomalies. For some critical units in network, their periodical monitoring allows a continuous tracking of the gas development as an early alert in case of failure. For instrument transformers, a mix of predictive tasks such as DGA, UHF and electric on-line PD detection and tg δ are used as a routine.

Infrared Thermography (IR) is performed over all the HV substations twice a year. Having shown as a valuable tool to detect early thermal anomalies and to identify patterns of failure, by executing IR inspections many maintenance tasks were modified; in the case of critical disconnectors in network, their WPro originally time-based, were turned into condition-based and they are only taken out of service if any thermal abnormality is detected.

Over some items, a number of on and off-line predictive measures are executed to assess their condition and/or define the need of executing major maintenance tasks. For surge-arresters, IR scans, leakage current and PD measuring are carried out. In circuit-breakers (CBs), operating time and contact resistance are measured; in SF_6 CBs gas pressures and leakages are monitored, for minimum-oil CBs, water-in-oil content and breakdown voltage determinations are made, in pneumatic CBs dew point in air is verified.

In addition, on-line detective maintenance tasks searching for hidden faults are performed. In substations with more than one HV busbar, the maintenance of busbar disconnectors is supported in a routine of IR scans and detective tasks. By the execution of opening and closing operating tests, measuring of the motor drive current and checking of interlocking and signaling, the item condition is verified and the need of programmed outages to execute repairing tasks is defined. When possible, repairs in service by Live Works (i.e. lubricating and contacts cleaning) are executed.

Additionally, the use of techniques based on the RCM (Reliability Centered Maintenance) methodology together with a FMECA approach, makes it possible to optimize the maintenance activities, customizing the tasks to be performed according to the different operating contexts.

By this approach, focusing on the particular requirements of each equipment and strengthening the performing of condition-based activities, more flexible WPro were developed, reducing the execution of unnecessary maintenance tasks and increasing the availability of the installations.

MAP OF RISK OF THE HV NETWORK

Aiming at defining the levels of criticality of the installations, a risk analysis was carried out, by the development of a "*map of risk*" of the whole HV network.

Risk analysis is based on probabilities and possible consequences of different events for different types of equipment [3].

As a basis for the risk analysis, the concept of *risk matrix* has been used, to provide an efficient way of showing the combination of probability and consequences for different relevant unwanted events which can occur.

Risk matrices divided into three areas, *"Low"*, *"Medium"* and *"High"* (unacceptable) were developed for every "module of maintenance". The development of a "*map of risk*" of the HV network according to critical degrees, allowed identifying the most vulnerable items in the grid, for having in case of failure a higher impact in the quality of supply.

As from the risk classification performed, priorities for the maintenance of the equipment were defined, in order to assign the resources required to reduce levels of risk and maintenance activities were addressed for the different components in a differentiated way, considering the risk assessment of the HV network as a whole (*Fig. 3*).

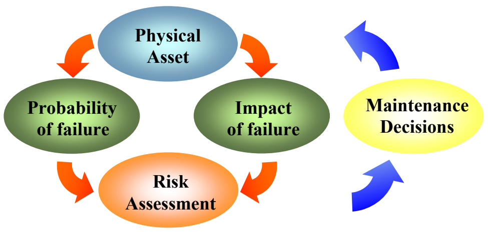

Fig. 3 - Decision Scheme of the Risk Analysis

MANAGEMENT OF MAINTENANCE SKILLS

A key factor for the success of this maintenance model is the development of highly qualified manpower.

To perform the maintenance process in the most cost-effective way, part of traditionally in-house maintenance tasks were outsourced. From this determination, focus was put on preserving in the company the know-how of the activities, strategic core skills that cannot be deprived under any circumstances [4]. In this way, personnel cost could be downsized outsourcing some maintenance activities and specific knowledge in the field of HV maintenance equipment was concentrated.

As a result, a strong emphasis was put on the training of specialized in-house and outsourced work teams, improving continuously and updating their knowledge and skills. Thus, a best value was added to the maintenance activities**,** not only in a profitable way but also through seeking additional advantage in terms of quality, performance and service improvement.

OBTAINED RESULTS

Through the model developed, outages could be optimized to perform maintenance tasks, unifying technical criterions to be followed, categorizing the abnormalities detected according to severity levels to prioritize the corrective actions to execute and controlling the obtained results.

This strategy is supported by a strong tendency toward the execution of predictive (on and off-line) tasks to assess the condition of the equipment, detective actions searching for hidden faults and the use of risk based techniques.

The extended use of this management model, has allowed reaching positive results as regards the improvement of the maintenance management, diminishing outages of the equipment and increasing the availability of the installations, making it possible to reduce maintenance costs.

A survey of the evolution of a number of balanced scorecards and key performance indicators (i.e. number of unwanted events, number of interruptions, number of programmed outages, maintenance costs, quality of supply), shows the enhancement achieved by its development concerning the efficiency of the maintenance management as a whole.

A further development is going in depth in a "*bay by bay*" differentiated maintenance, according to criterions such as environmental pollution, equipment characteristics, role of the substation in the electrical system an so on, aiming at increasing the availability of the installations and improving the quality of supply in a cost-effective way.

CONCLUSIONS

In the context of the new electric markets it is essential to reduce programmed outages in number and duration. To face this situation, an optimized maintenance management model for H.V. substations, has been developed.

This management model put a strong emphasis on the execution of proactive maintenance tasks and takes into account the "*map of risk*" of the HV network, to identify the levels of criticality of the installations.

The results from its use at Edenor have proved to be highly positive in terms of improvement of key performance indicators and reduction of costs.

The model outlined has proved being useful for distribution companies that operate into a competitive environment and regulated markets with strict technical requirements to fulfill. This thread encourages to continue going in depth into its development, to successfully afford the changing environment for distribution utilities.

REFERENCES

[1] Groot, E. et al, Successful Implemented Condition Based Maintenance Concept for Switchgear, *17th CIRED Conf.* - Paper 1.14 (Barcelona, 2003).

[2] Cliteur, G., Wetzer, J., Condition Assessment of Power Transmission and Distribution Components, *16th CIRED Conf.* - Paper 1.26 (Amsterdam, 2001).

[3] Nordgård, D. et al, Developing and Implementing a Risk Based Maintenance Strategy for Distribution Companies, *18th CIRED Conf.* - Paper 292 (Turin, 2005).

[4] Wester, P. et al, Outsourcing Maintenance Processes in Electricity Utilities, *16th CIRED Conf.* - Paper 6.18 (Amsterdam, 2001).